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published in
Journal of Experimental Psychology: Human Perception and Performance
1997

DOI (link to publisher)
10.1037/0096-1523.23.3.756

document version
Publisher's PDF, also known as Version of record

Journal of Experimental Psychology:
Human Perception and Performance
1997, Vol. 23, No. 3, 756–767

0096-1523/97/$3.00

Stimulus–Target Compatibility for Reaching Movements

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Reaction time, movement time, and initial direction of reaching movements toward a target in left or right hemispace were measured. In Experiment 1, the target of movement and hand had to be selected; movements toward the imperative stimulus were initiated faster than movements toward the alternate target, and ipsilateral reaches were initiated faster than contralateral reaches. In Experiment 2, the difference between ipsilateral and contralateral reaches disappeared when no selection of the hand had to occur. In Experiment 3, no target had to be selected, and only a stimulus–hand compatibility effect appeared. The results reveal different compatibility effects (stimulus–target, stimulus–hand, target–hand), implying that participants exploit different correspondences, depending on the degrees of freedom of the action. The notion of compatibility effects relating to movement targets offers a new perspective on the negative Simon effect and it questions the general concept of response codes.

One of the longest standing explanations for Simon effects and, possibly, spatial compatibility effects is Simon's (1990) thesis that there is a "natural tendency to react toward the source of stimulation" (p. 34; Simon, 1969; Simon & Rudell, 1967). In the spatial compatibility task, the position of the stimulus is the task-relevant attribute and, in the Simon task, the position of the stimulus is the task-irrelevant attribute. In both paradigms, spatial stimulus–response (S–R) correspondence speeds up reaction time (RT) (see Simon, 1990, for a comprehensive review of the Simon effect). Even though Simon's thesis is not without its critics, especially as regards the Simon effect (e.g., Umiltà & Nicoletti, 1990), it is nevertheless surprising that compatibility studies in which participants are actually asked to move toward the stimulus have been few and far between (e.g., Simon, Craft, & Webster, 1971). The usual responses solicited from participants are keypresses, joystick, or toggle-switch deflections or movements toward a button that is not the imperative stimulus. As a result, it is unclear whether Simon's hypothesis is literally true. In general, it is fair to say that little is known about the effects of types of movements in the compatibility paradigm and whether characteristics of an action other than its latency also reveal S–R compatibility.

Inattention to aspects of action in the compatibility paradigm is likely rooted in the common emphasis on the mental coding of responses along various dimensions (Kornblum, Hasbroucq, & Osman, 1990; Proctor & Reeve, 1990; Wallace, 1971). Coding theory appears to assume that either the organization of the emerging action is irrelevant to compatibility (". . .[S–R] compatibility effects are independent of the means by which. . .the response [code] is effected" [Proctor, Van Zandt, Lu, & Weeks, 1993, p. 82]) or that execution follows so simply and directly from simple response codes (like left and right) that attention to coordination is unnecessary. The latter is untenable for reasons most clearly articulated by Bernstein's (1967) exposition of the degrees of freedom problem; the former is contradicted by a growing number of empirical observations.

The following observations suggest that the manner of response execution figures significantly into compatibility effects. In choice RT with orthogonal S–R directions (e.g., up–down stimuli and left–right responses), observed compatibility effects were shown to depend on handedness in the bimanual case (Ladavas, 1987) and on responding hand (Bauer & Miller, 1982), hand position (Michaels, 1989; Weeks, Proctor, & Beyak, 1995), and hand posture (Michaels & Schilder, 1991) in the unimanual case. In other paradigms, the speed of an upcoming movement was shown to affect its latency (Spijkers, 1990; Spijkers & Sanders, 1984). Finally, and perhaps most important, Tipper, Lortie, and Baylis (1992) showed, in an experiment that involved reaching next to illuminated targets, that the position of the effector and action goals determine priming and interference effects. Together, these effects suggest that action-system variables, in addition to the usually studied codes (which hand responds, where that hand is, or the *relative* direction in which it moves), might be important to compatibility.

The three experiments reported here investigated one aspect of reaching actions, the target toward which the reach was directed, and whether and under what circumstances that aspect entered into compatibility effects. In the general paradigm, there are left and right stimulus lights, one of which is illuminated as an imperative to a reaching movement, which has to be initiated as quickly as possible. The targets of reaching movements are either the illuminated stimulus light itself or the other, unilluminated stimulus. Participants are sometimes asked to make ipsilateral move-

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ments (e.g., the left hand moving to the left target) and, at other times, contralateral movements (e.g., the left hand moving to the right target).

There are (at least) three spatial correspondence relations in this paradigm (see Table 1; see also Figure 1): one between the position of the stimulus and the position of the movement target (S–T); one between the position of the stimulus and the position of the hand (S–H); and one between the position of the target and the position of the hand (T–H). The observation of an S–T compatibility effect would be a faster initiation of reaching to an illuminated stimulus than to the other target. Such effects have been found in eye movements; saccades toward a stimulus have shorter latencies than those away from the stimulus, called anti-saccades (e.g., Fischer & Weber, 1992). An S–H effect would constitute a classical spatial compatibility effect in that RTs would be relatively fast when the stimulus and the responding hand correspond spatially. Finally, a T–H effect would reflect a spatial compatibility effect between which hand must respond and where it must go.

The recording of hand movements permits the measurement of RT, movement time (MT), and the movement trajectory (although we limit ourselves here to initial movement direction [IMD]). All three dependent variables may reflect the correspondences listed in Table 1. With regard to this task and these variables, we ask (a) which of the spatial correspondences enter into compatibility effects and (b) whether compatibility effects in the RT exhibited by these variables are also reflected in MT and in the direction of initial movement. Question (a) is inspired by Simon's *tendency thesis*, in that it is not known whether the hypothesized tendency to react toward the source of stimulation reflects a tendency to perform an actual movement toward the stimulus or whether it reflects a tendency to make a response with a hand that is located on the same side as the stimulus. So our question is whether the compatibility (or Simon) effects are relations between stimulus position and effector location or between stimulus position and effector destination, or both. If the emphasis on the spatial correspondence between stimulus position and effector position is correct, spatially corresponding S–H pairs will give rise to relatively fast RTs, regardless of the direction of movement of the effector. However, if the emphasis on the correspondence between stimulus position and direction of movement is correct, S–T pairs that spatially correspond will be relatively fast. Question (b) reflects an interest in whether the hypothesized "tendency to react toward the source of stimulation" can be observed for the temporal and spatial aspects of the trajectories of hand movements. It might be the case, for example, that if participants are required to move to the unilluminated stimulus, their initial movement direction is curved toward the illuminated stimulus.

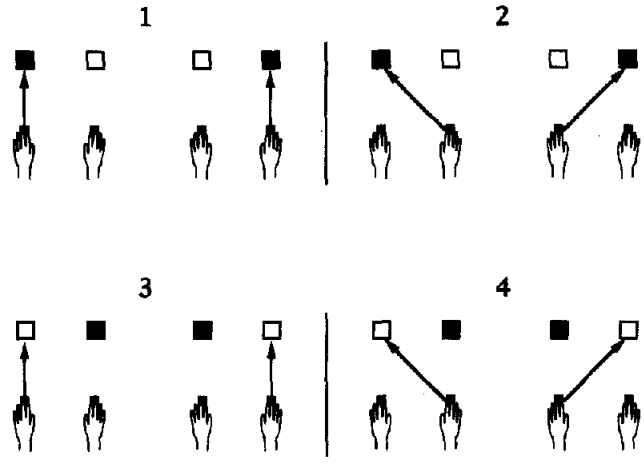

Figure 1. The types of trials and their blocking in Experiment 1. There were four blocks of trials, as indicated by the numerals 1 to 4, each consisting of two types of trials, corresponding to the illumination of the left and right imperative stimulus. The black squares represent the illuminated stimuli; the white squares represent the nonilluminated ones. The arrows denote the required movement.

Table 1
Spatial Correspondences in Experiments 1–3

Stimulus	Target	Hand	Spatial correspondences S–T	S–H	T–H
left	left	left	+	+	+
left	left	right	+	−	−
left	right	left	−	+	−
left	right	right	−	−	+
right	right	right	+	+	+
right	right	left	+	−	−
right	left	right	−	+	−
right	left	left	−	−	+

Note. The signs + and − indicate spatial correspondence and noncorrespondence, respectively. S–T = relation between position of stimulus and position of movement target; S–H = relation between position of stimulus and position of the hand; T–H = relation between position of target and position of the hand.

The paradigm used here is, in some ways, an action complement to experiments that examined compatibility effects of the destinations of (apparently) moving stimuli (Michaels, 1988; Proctor et al., 1993). In the Michaels experiment, participants had to push a left or a right joystick in response to a moving stimulus. One of two squares on a screen appeared to move toward the ipsilateral hand (i.e., it expanded symmetrically) or toward the contralateral hand (i.e., it expanded and translated). In the conditions of interest, participants had to respond (compatibly or incompatibly) to the destination of apparent motion of the stimulus. A compatibility effect for destination was observed whereby a left response to a stimulus moving toward the left hand and a right response to a stimulus moving toward the right hand were initiated faster than the converse pairings. In our experiments, the question is whether compatibility effects are also seen with the destination of moving hands.

Experiment 1

This experiment examines which of the three correspondence relations given in Table 1 yields compatibility effects when the participants have to perform an actual reaching movement to a target, which may or may not correspond to the position of an imperative stimulus.

Method

Participants. Eight students at the Vrije Universiteit participated in this experiment. All were right handed, and they were paid a small fee for their participation.

Apparatus and stimuli. The participants were seated at a table covered with an aluminum sheet, into which four light-emitting diodes (LEDs) were embedded. The LEDs were covered with a green plastic cover so that when an LED was lit, a green stimulus (1 cm × 1 cm) appeared. The unilluminated LEDs could still be perceived clearly as dark green squares. The LEDs were recessed so that the surface was smooth. The LEDs were arranged in a square 30 cm × 30 cm.

Participants inserted two or three fingers (depending on finger size) in the side of two small boxes, which could be moved independently across the table. The boxes consisted of a 5 cm × 3.5 cm base, and three 1.5-cm high edges (two on each side and one at the front). The boxes weighed 6 g each. The bottom of the boxes was covered with cloth so that they slid freely across the surface. Because movements consisted of sliding over the surface, they could be measured in the x–z plane with only one camera.

An infrared, light-emitting diode (IRED) was attached to the front of each box. A flexible wire connected the box to the computer. An infrared (SELSPOT) camera, above the table, sampled the x–z coordinates of the IREDs at 320 Hz. Data registration, illumination of the measurement IREDs, illumination of the stimulus LEDs, and control of camera onset and offset were performed by a computer.

Procedure and design. At the beginning of a trial, the participants positioned the moveable boxes over the two proximal (always unilluminated) LEDs. The distance between the starting position of the hands and the body was approximately 40 cm. Participants were told to make a rapid unimanual movement, upon stimulus onset, to the distal, target LED. In the S–T consistent condition, the target was the illuminated stimulus (panels 1 and 2 of Figure 1); in the S–T inconsistent condition, the target was the unilluminated stimulus (panels 3 and 4 of Figure 1). Within each condition, there were two subconditions of movement type. The participants either made an ipsilateral movement (i.e., the left hand moving from its left starting position to the left target or the right hand moving from its right starting position to the right target; panels 1 and 3 of Figure 1) or a contralateral one (i.e., left hand to right target or right hand to left target; panels 2 and 4 of Figure 1). The experiment was divided into four blocks of 50 trials, corresponding to the panels of Figure 1, with an equal number of left and right stimuli randomly ordered. Each block was preceded by 10 practice trials, which were not analyzed further.

Half of the participants performed the consistent S–T mapping in the first two blocks of trials and the inconsistent S–T mapping in the next two blocks of trials. This order was reversed for the other participants. Under both S–T mappings, half of the participants started with a block of trials requiring an ipsilateral movement, followed by a block of trials requiring a contralateral movement. This order was reversed for the other participants.

Each trial started with a warning signal: The two stimulus LEDs were illuminated simultaneously. After 1 s, the LEDs went off for 1 s, after which one of the two was illuminated for 500 ms. The participants were instructed to make a fast reaching movement[1] toward the target and immediately return to the home location. Speed, rather than terminal accuracy, was emphasized to minimize accuracy-based speed differences. The position of the stimulus light, in combination with the instructions for that block to make a particular response (i.e., respond ipsilaterally or contralaterally and respond toward the illuminated or the unilluminated stimulus), defined the correct response. Participants were told not to lift the boxes from the table during the movement but to slide them over the surface of the table.

Movement recording began at stimulus onset and lasted 1,500 ms. Only the position data of the hand that had to make the required response on a given trial were sampled so that no data were obtained for the other hand that, on some occasions, (erroneously) started to move. The intertrial interval was about 10 s (the time that it took the computer to store the data and generate the next trial).

Data analysis. The movement data were low-pass filtered with a cut-off frequency of 10 Hz (second-order recursive Butterworth). The RTs (i.e., the time interval between stimulus onset and initiation of the movement) were calculated from the movement data: An algorithm searched backward in time from the peak velocity to the point at which the velocity dropped below 4 cm/s (cf. Zelaznik, Schmidt, & Gielen, 1986); this point was called the *start of the movement.* For calculation of the MT, a movement was said to be completed when the velocity reached its minimum or when it dropped below 4 cm/s.

IMD was calculated from the least-squares linear fit of the first 10% of the movement data following the onset of the movement, as defined above. The angle between this line and a reference line, connecting the starting position and the target, was computed. This angle was taken to be a measure of initial movement direction (cf. de Graaf, Sittig, & Denier van der Gon, 1994). Positive angles for ipsilateral movements were deviations away from the body midline, whereas negative angles were deviations toward the body midline. Similarly, for contralateral movements, positive angles were deviations away from the body, whereas negative angles were deviations toward the body.

Results

Only the correct trials (i.e., the ones in which the reach arrived at the required target position) and trials on which the RT was within the range of 150–1,000 ms were analyzed. The trials on which the approach movement, after an initial acceleration phase, decelerated and subsequently started accelerating again (presumably as the result of hesitation or an abrupt change in direction) were counted as incorrect trials. Two percent of the trials fell into these categories.[2]

We performed three-factor, within-individuals analyses

[1] Although the responses solicited from the participants would be more properly considered to be sliding movements, we will simply refer to them as *reaching movements.*

[2] A preliminary analysis revealed that the standard deviations of the end points of the movement were, in general, below 1 cm, which we take to indicate that the movements were directed at the required target position. Therefore, and because of the instructions' explicit emphasis on speed, no analysis on the terminal accuracy was performed.

of variance (ANOVAs) on the RTs, the MTs, and the IMDs, using Mapping (consistent vs. inconsistent S–T mapping), Movement Type (ipsilateral vs. contralateral movements) and Stimulus Position (left vs. right) as factors.

The mean RTs, the mean MTs, and the mean IMDs for the S–T mapping by movement type subconditions are shown in Table 2 (along with the results of Experiments 2 and 3). For the RTs, the main effect of mapping was significant, $F(1, 7) = 19.94$, $p < .01$. This effect signalled a 50-ms advantage for movements toward the illuminated stimulus over movements toward the unilluminated stimulus (282 ms vs. 332 ms, respectively). In addition, the main effect of movement type was significant, $F(1, 7) = 37.67$, $p < .001$; there was a 27-ms advantage of ipsilateral movements over contralateral movements (293 ms vs. 320 ms, respectively). No other effects reached significance. In short, there were two operative correspondence relationships: the stimulus position–target position relationship (consistent vs. inconsistent S–T mapping) and the target–hand relationship (ipsilateral vs. contralateral movements). Note, from Table 2, that these relationships were strictly additive. No compatibility effect for stimulus position–hand was observed.

For the MTs, only the main effect of movement type was significant, $F(1, 7) = 79.56$, $p < .001$. The mean MTs for the ipsilateral movements were 359 ms, and the mean MTs for the ($\sqrt{2}$ longer) contralateral movements were 420 ms.

For the IMDs, the main effect of movement type was significant, $F(1, 7) = 53.58$, $p < .001$; the IMDs for the ipsilateral movements were, on average, −20°; whereas the IMDs for the contralateral movements were close to 0°. Thus, initially, ipsilateral movements lay medial to the reference line, whereas contralateral movements hardly deviated from the reference line. Given that the Movement Type × Mapping interaction did not reach significance, the IMDs did not provide evidence for a tendency to move initially in the direction of the illuminated stimulus.

Discussion

Of the three correspondence relations enumerated earlier, two appeared to be operative in this experiment. First, there was an S–T effect; participants tended to initiate their movements faster when they had to move toward the illuminated stimulus (i.e., when stimulus position and target position coincided) than toward the unilluminated stimulus. Second, a T–H effect occurred; ipsilateral movements were initiated faster than contralateral movements. The combination of S–T and T–H compatibility effects mirror the results from the Michaels (1988) experiment with apparently moving stimuli, wherein a main effect of mapping and an effect of stimulus type were observed (stimuli moving ipsilaterally were responded to faster than stimuli moving contralaterally).

The absence of an interaction between mapping and movement type indicates that S–H spatial correspondence did not enter into a compatibility relationship. This observation is corroborated by the analysis of the IMDs, which found no evidence for a tendency to react initially toward the source of stimulation. In short, it appears that moving toward the imperative stimulus is easier than moving toward

Table 2
Mean RTs (in ms), Mean MTs (in ms), and Mean IMDs (in Degrees) for the S–T Mapping by Movement Type Subconditions, Averaged Over Stimulus Position, for Experiments 1–3

Experiment: selection	Consistent S–T mapping		Inconsistent S–T mapping	
	Ipsilateral movement	Contralateral movement	Ipsilateral movement	Contralateral movement
	X O | L R	O X / L R	X O | L R	O X \ L R
		Mean RTs		
1: Hand + target	270	294	316	347
2: Target	281	279	317	315
3: Hand	303	337	347	306
		Mean MTs		
1: Hand + target	362	424	355	417
2: Target	374	421	366	419
3: Hand	365	400	358	412
		Mean IMDs		
1: Hand + target	−19	0	−20	0
2: Target	−14	7	−15	4
3: Hand	−14	3	−15	0

Note. In the schematic insets, X indicates the illuminated stimulus and O, the unilluminated stimulus; L and R indicate the left and right hands, and the line, the direction of movement. RT = reaction time; MT = movement time; IMD = initial movement direction; S–T = relation between position of stimulus and position of movement target.

some other place, regardless of the spatial relationship between the position of the illuminated stimulus and the responding hand, and that the effect shows up only in the RTs and not in the kinematics of the movement. A comparable result was obtained in a selective reaching task (Jackson, Jackson, & Rosicky, 1995) in which the participants had to reach and grasp an object that was sometimes accompanied by a distractor object. Under normal viewing conditions, the reach and grasp kinematics showed no distractor interference.

The general pattern of RT results is remarkably similar to those of Wallace (1971) and Riggio, Gawryszewski, and Umiltà (1986) who used, respectively, crossed and uncrossed hands pushing keys and crossed and uncrossed hand-held sticks pushing keys. As in our experiment, these authors found two compatibility effects. First, if the position of the response key and the position of the stimulus corresponded spatially the RTs were relatively short. Second, RTs were shorter when the response effectors (i.e., hands or sticks) were uncrossed than when they were crossed. The former effect is similar to our mapping effect (consistent vs. inconsistent S–T mapping); the latter effect is similar to the effect of movement type (ipsilateral vs. contralateral movements). What is notably different about our experiment is that the crossing is not embodied in the experimental setup; the crossing (i.e., making a contralateral response) takes place only after stimulus presentation. Wallace (1972) replicated the crossed-hands effect with sight of the hands occluded and concluded that the effect was based on kinesthetic information about hand position. The current results suggest that an intention to make a crossed movement is sufficient to observe the crossing effect.

Experiment 2

Experiment 1 demonstrated that a contralateral movement took longer to initiate than an ipsilateral movement. This effect might be due to the spatial incompatibility between hand and target, in that, with contralateral movements, the direction of movement of the hand differs from its initial position. However, it might also be the case that a contralateral movement is simply more difficult to perform, for example, because a greater distance has to be covered or because the movement is of a significantly longer duration. Whether the characteristics of contralateral movements as such or whether the target–hand incompatibility was responsible was addressed in this experiment.

A parallel issue was addressed by Nicoletti, Umiltà, and Ladavas (1984) in their replication of Wallace's (1971) study; both studies found a disadvantage of crossing the hands in a choice RT situation. Nicoletti et al. argued that this effect might have been due simply to the uncomfortable positioning of the arms; but this hypothesis was discarded because the disadvantage disappeared in a simple RT condition in which the participants always had to press the same key in response to a left–right stimulus. Nicoletti et al. concluded that, in a crossed-hands situation, the spatial incompatibility between the position of the responding hand and its identity becomes important only when a hand has to be selected. If selection of the hand is necessary to obtain a compatibility effect, then we would expect the difference between ipsilateral and contralateral movements to disappear if, in a block of trials, which hand is to respond is known in advance. If, on the other hand, contralateral movements are intrinsically more difficult to perform, then the effect should persist even if no hand selection has to take place.

It should be noted, however, that Nicoletti et al.'s (1984) simple RT study does not exclude the possibility that the crossed-hands effect was contingent on the selection of the target instead of on the selection of the hand because, in the choice RT situation, both a hand and a target had to be selected; whereas in the simple RT situation, the participants did not have to choose a hand nor did they have to discriminate the stimulus. If target selection is important, the effect of the movement type should persist only if the selection of the target has to take place. If, on the other hand, the effect of the movement type becomes apparent *only* when an effector has to be selected, then the effect should disappear. Therefore, in this experiment, we eliminated the uncertainty about which hand was to make the response. The same combinations of S–T mapping, movement type, and stimulus position were used as in Experiment 1 but in a different order. Within a block, combinations were blocked in different groups. The participants always performed a movement with the same hand (i.e., they only had to select the target), but the movement type varied on a trial-to-trial basis.

Method

Eight new right-handed students at the Vrije Universiteit participated. The apparatus and stimuli were the same as in Experiment 1. The procedure and design were the same as in Experiment 1, except for the blocking of trials and the instructions given to participants (Figure 2). The participants again had to perform a consistent or an inconsistent S–T mapping, but the responding hand was fixed in a given block of trials. The fingers of the responding hand were inserted in an IRED marker box; the other hand rested on the participant's lap. On S–T consistent trials, the participants reached to the illuminated target (which was either left or right; panels 1 and 2 of Figure 2); on S–T inconsistent trials, they reached toward the unilluminated target (panels 3 and 4 of Figure 2).

Half of the participants performed the consistent S–T mapping in the first two blocks of trials and the inconsistent S–T mapping in the next two blocks of trials. This order was reversed for the other participants. Under both S–T mappings, half of the participants started with a block of trials using the right hand, followed by a block of trials using the left hand. This order was reversed for the other participants.

Results

Incorrect trials, as defined in Experiment 1 (1.8%), were not analyzed further. The mean RTs, the mean MTs, and the mean IMDs for the S–T Mapping × Movement Type subconditions are shown in Table 2. An S–T Mapping ×

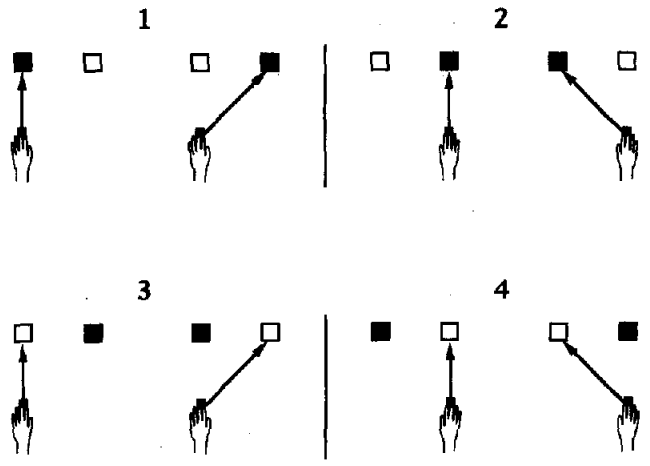

Figure 2. The blocking of trials in Experiment 2. There were four blocks of trials, as indicated by the numerals 1 to 4, each consisting of two types of trials, corresponding to the illumination of the left and right imperative stimulus. The black squares represent the illuminated stimuli; the white squares represent the nonilluminated ones. The arrows denote the required movement.

Movement Type × Stimulus Position ANOVA on RTs yielded only one significant effect, the main effect of mapping, $F(1, 7) = 11.92$, $p < .02$. On average, the RTs in the S–T consistent mapping condition were 280 ms; in the S–T inconsistent mapping condition, the RTs were 316 ms. Contralateral and ipsilateral responses did not differ; indeed, their average RTs were within 2 ms of each other. Thus, only one of the three correspondence relations (see Table 1) was operative—that between stimulus and target.

For the MTs, the main effect of movement type was significant, $F(1, 7) = 75.36$, $p < .001$; ipsilateral movements had shorter durations than contralateral movements (370 ms vs. 420 ms, respectively). In addition, the S–T Mapping × Stimulus Position interaction was significant, $F(1, 7) = 12.38$, $p < .01$; movements directed to the left target were 3 ms shorter in duration than movements directed to the right target.

For the IMDs, the main effect of movement type was significant, $F(1, 7) = 134.64$, $p < .001$. For the ipsilateral movements the IMDs were, on average, −15°; for the contralateral movements, the IMDs were 6°. Thus, initially, ipsilateral movement trajectories tend to lie toward the body midline, and the contralateral movement trajectories tend to lie away from the body. In addition, the three-way S–T Mapping × Movement Type × Stimulus Position interaction was significant, $F(1, 7) = 8.71$, $p < .05$. This interaction may be understood as an interaction of the movement type and the responding hand; the left hand exhibits a greater deviation from the reference line than does the right hand during ipsilateral movements, whereas no such effect occurs for the contralateral movements.

Discussion

In this experiment, as in Experiment 1, an effect of S–T mapping was observed; movements were initiated faster when targeted toward the illuminated stimulus. This effect appeared regardless of the spatial relation between hand and target, as evidenced by the absence of a main effect of movement type, and regardless of the spatial relation between stimulus position and hand position, as evidenced by the absence of a Mapping × Movement Type interaction. Thus, we infer that the effect of movement type observed in Experiment 1 is not due to the intrinsic difficulty of performing a contralateral movement; nor is the effect contingent on target selection, so that the alternative interpretation of Nicoletti et al.'s (1984) data may be discarded. Rather, it appears that, in accordance with Nicoletti et al., selection of the responding hand is a prerequisite for observing target–hand compatibility.

Contrary results on ipsilateral and contralateral movements were reported by Simon et al. (1971). In their Experiment 1, the participants reached with a single, centrally positioned index finger to target lights in the hand's ipsilateral or contralateral space. Shorter initiation times were observed for ipsilateral responses. In their experiment, however, only right-hand responses were emitted, so that it is unclear whether the observed difference was due to the spatial (non)correspondence between target and hand or to a preference for moving toward the right target position.

Experiment 3

Experiment 2 showed that if only the target, but not the hand, had to be selected, no effect of movement type emerged. Thus, the spatial (non)correspondence between the hand and the target positions is not effective in this situation. Thus, there is nothing intrinsically better about moving a right hand to a location in the right hemispace than to a location in the left hemispace. What is better is organizing an ipsilateral movement over a contralateral movement when the effector that has to perform the action is not known in advance. One may ask the same type of question about stimulus–target consistency: Is moving toward an illuminated target unequivocally better than moving toward an unilluminated one or is the effect contingent on selection of the target? This question may be answered by fixing, within a block of trials, the target location (so that the movement destination is always known in advance) and having the stimulus determine which hand to use. If target selection is a necessary condition for obtaining a stimulus–target effect, then the effect should disappear when the target is known in advance. If, on the other hand, a movement toward an illuminated target is an intrinsically preferred action, then the same stimulus–target compatibility effect, as observed in the previous experiments, would be expected. In addition, because in this experiment selection of the hand has to take place, an effect of movement type is again expected to occur.

Method

Eight new right-handed students at the Vrije Universiteit participated. The apparatus and stimuli were the same as in the

previous experiments. The procedure and design differed in the blocking of trials and in the instructions given to participants. The target location was known in advance and was held constant in a block of trials. Only the responding hand had to be selected as a function of the imperative stimulus. In half of the trial blocks, the left distal LED was designated as the target and in the other half of the blocks, the right LED served as the target. In the stimulus–hand consistent mapping, the participant was to move the hand that was ipsilateral to the stimulus toward the target location (panels 1 and 2 of Figure 3); in the stimulus–hand inconsistent condition, the left stimulus signalled a right-hand response and the right stimulus signalled a left-hand response (panels 3 and 4 of Figure 3). Unlike Experiments 1 and 2, the consistency of the S–T combination and the movement type varied on a trial-to-trial basis; in this design, the right hand can perform a consistent S–T mapping (i.e., it moves to the illuminated stimulus), whereas the left hand performs an inconsistent one (i.e., it moves to the unilluminated stimulus).

Half of the participants began with two blocks of trials in which the spatial relation between stimulus position and hand position corresponded and ended with two blocks in which stimulus position and hand did not correspond. This order was reversed for the other half of the participants. Under both spatially corresponding (i.e., between the hand and the stimulus) blocks, half of the participants started with a block of trials requiring a movement toward the right target (panels 2 and 4 of Figure 3), followed by a block of trials requiring a movement toward the left target (panels 1 and 3 of Figure 3). This order was reversed for the other half of the participants.

Results

Incorrect trials (3.8%) were not analyzed further. The mean RTs, the mean MTs, and the mean IMDs for the S–T mapping by movement type subconditions are shown in Table 2. An S–T Mapping × Movement Type × Stimulus Position ANOVA on RTs yielded only one significant effect, the S–T Mapping × Movement Type interaction, $F(1, 7) = 12.08$, $p < .02$; the RTs of trials in which the position of the stimulus corresponded with the position of the hand were, on average, 38 ms shorter than the RTs of the noncorresponding trials. Between the two conditions in which the stimulus and the hand corresponded spatially (panels 1 and 2 of Figure 3), there was no hint of a stimulus–target effect, as was observed in the previous experiments (303 ms vs. 306 ms). Post hoc tests showed that the 10-ms difference in the conditions in which the stimulus and the hand were spatially noncorresponding (panels 3 and 4 of Figure 3) was not statistically reliable.

For the MTs, as in Experiment 1, only the main effect of movement type was significant, $F(1, 7) = 95.83$, $p < .001$. MTs for the ipsilateral movements were, on average, 361 ms, MTs for the contralateral movements were 406 ms.

For the IMDs, the main effect of movement type was significant, $F(1, 7) = 31.09$, $p < .001$. Again, ipsilateral movements initially lay medial to the reference line (−14°), whereas the contralateral movements exhibited almost no deviation from the reference line (1°). Contrary to the previous experiments, the main effect of S–T mapping was significant, $F(1, 7) = 9.31$, $p < .02$. The IMDs for the S–T consistent and S–T inconsistent condition were, on average, −5° and −8°, respectively. Again, the absence of an S–T Mapping × Movement Type interaction indicates no tendency to move toward the source of stimulation.

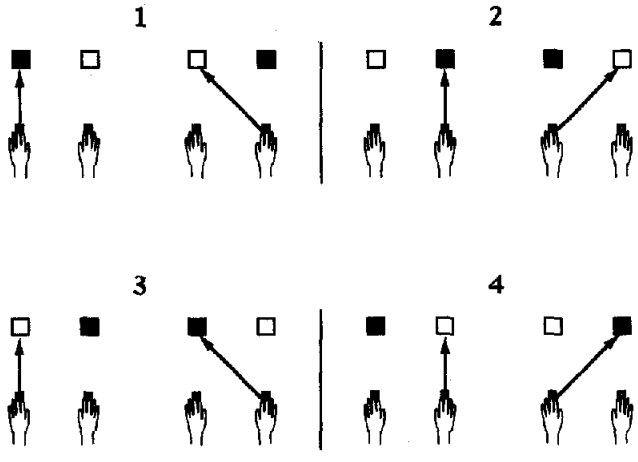

Figure 3. The blocking of trials in Experiment 3. There were four blocks of trials, as indicated by the numerals 1 to 4, each consisting of two types of trials, corresponding to the illumination of the left and right imperative stimulus. The black squares represent the illuminated stimuli; the white squares represent the nonilluminated ones. The arrows denote the required movement.

Discussion

Experiment 3 revealed that when only a hand has to be selected, but not the target, RTs were shorter when the stimulus position and the responding hand corresponded spatially than when they did not. This finding resembles a typical spatial S–R compatibility effect; left-hand responses to left stimuli and right-hand responses to right stimuli were relatively fast. Contrary to the previous experiments, the relation between the stimulus and the target did not matter; participants were equally fast when they reached toward an illuminated target than toward an unilluminated one. In addition and contrary to our expectations, there was no bias to initiate ipsilateral responses faster than contralateral ones.

These observations parallel those of Experiment 2 in which only a stimulus–target compatibility effect was observed when a target had to be selected. It appears, therefore, that when the hand need not be selected (Experiment 2), no compatibilities involving the hand were operative; and when the target need not be selected (Experiment 3), no compatibilities involving the target position were operative. In Experiment 1, when both choice of target and of hand awaited stimulus appearance, both the stimulus–target and the hand–target correspondence additively affected RT, but not the stimulus–hand correspondence, which was found to be operative in Experiment 3. Finally, the effects of MT and IMD were comparable to the results obtained in the previous experiments.

General Discussion

In three experiments, participants reached with an ipsilateral or a contralateral hand movement toward a target location. The target was either the imperative stimulus itself or the other, unilluminated stimulus. The three experiments had precisely the same stimuli, targets, and responses, but they were blocked differently such that within a block, different pairs of the eight combinations (see Table 1) occurred. In all experiments, there were three dependent measures. The initial direction of movement showed minor deviations from straight-line paths to the target, but these deviations were not systematically related to the spatial correspondence between stimulus position and hand. Movement times showed the predictable T–H correspondence; the longer, contralateral movements took more time than the shorter, ipsilateral movements. Movement initiation time, RT, did show dramatic and differential effects among experiments, indicating that this dependent measure reveals most clearly the compatibilities in our experiments.

The primary issue in Experiment 1 was whether a compatibility effect would occur for the destination (target) of an upcoming movement. First, a strong compatibility effect was observed; when the position of the stimulus and the target location corresponded spatially RTs were shorter than when they did not correspond. Second, RTs were shorter when the position of the hand and the position of the target corresponded spatially; ipsilateral movements were initiated faster than contralateral movements. In Experiment 2, responses within a block were made by a single hand. An S–T mapping effect was observed, as in the previous experiment, but no effect of movement type, which suggested that the prerequisite for an effect of movement type was the selection of the responding hand. Finally, Experiment 3, in which the target was held constant within a block, exhibited only an S–H compatibility effect; RTs were shorter when the stimulus position and the position of the effector corresponded spatially, regardless of whether the reaching movements were ipsilateral or contralateral and of whether the reach was directed at the illuminated or the unilluminated stimulus. These latter findings suggest that, for the effect of movement type to appear, both a target and an effector have to be selected, as appeared to be the case in Experiment 1.

Selective Exploitation of Correspondences

Our first conclusion concerns the selective exploitation of the different, simultaneously available, spatial correspondence relations. Each of the three spatial correspondence relations (S–T, S–H, and T–H) yielded compatibility effects in at least one of our three experiments, and each failed to yield a compatibility effect in at least one other experiment, contingent on how the correspondences were sorted into blocks. Note that all experiments used identical S–R combinations, but different groupings and instructions were used, giving rise to different compatibility effects. Clearly, the structure of the task is a strong determinant of which of the possible compatibility effects emerges. First, the operative correspondence depends on the degrees of freedom of the action; for example, a correspondence of T–H or S–H will be operative only when the hand must be selected. Second, and relatedly, it appears that, when correspondences were mixed in a block of trials (e.g., the S–T consistency of Experiment 3), no compatibility effects involving this factor were operative, as opposed to the spatial correspondences that were constant in a block of trials (e.g., the S–T consistency of Experiment 2). Put differently, if a correspondence relation could not be exploited reliably within a block of trials, it was apparently not exploited at all. Participants do not appear to decide after stimulus presentation which correspondence to attend to. Related results were obtained by Van Duren and Sanders (1988), who found that compatible and incompatible S–R pairs that were blocked gave rise to stronger compatibility effects than the same compatible and incompatible S–R pairs that were mixed in a single block.

It is worth noting that the data seem to suggest that, although each of the three correspondences gave rise to a compatibility effect in at least one of the experiments, some correspondences appear to be more readily exploited than others. More specifically, the comparison between the compatibility effects observed in Experiments 1 and 3 suggests that the spatial correspondence between the stimulus and the hand imposes less severe constraints on the initiation of the movement than the other correspondences. In the S–T inconsistent–contralateral condition of Experiment 1 (panel 4 of Figure 1), RTs were the slowest, although in this condition the stimulus and the hand always corresponded spatially (see Table 1). Because in this condition the direction of movement for each hand was always known in advance, participants only needed, in principle, to let the stimulus determine which hand to use. Apparently, the participants did not exploit this compatibility, although they did so in Experiment 3. In addition, the trend for the overall RTs to be slowest in Experiment 3 seems to indicate that the S–H correspondence is less preferred than the other compatibilities. A similar conclusion was reached by Klapp, Greim, Mendicino, and Koenig (1979), who argued that responses are coded more readily in terms of environmental goals than in terms of the anatomical effectors required to accomplish these goals. More recently, Heister, Schroeder-Heister, and Ehrenstein (1990) proposed a model based on the relative dominance of some spatial compatibilities over others. They argued that the compatibility between the position of the stimulus and the position of the response keys operates more strongly than the compatibility between the position of the stimulus and the position of the effectors, which, in turn, operates more strongly than the compatibility between the position of the stimulus and the anatomical left–right identity of the response effectors.

However, the hierarchical model proposed by Heister et al. (1990) lacks an explicit account of why some compatibilities are more dominant than others, and we propose a tentative explanation on the basis of a consideration of differences in target specification by the stimulus across the experiments. In all our experiments, the position of the stimulus conveyed information about the required response.

In Experiment 1, the stimulus signalled[3] a place toward which to move (i.e., the stimulus itself, or the other, unilluminated target), whereas in Experiment 3, the stimulus signalled a to-be-moved hand. Because the target position was always known in advance in Experiment 3, the stimulus conveyed no information about the target but only about which hand had to be moved and, thus, the stimulus–hand compatibility became operative. The difference between Experiments 1 and 3 seems to indicate that the stimulus constrains the target of a movement more readily than it constrains which hand is to be moved. Given this reading, the proper level of description of a stimulus (and hence, of compatibilities) may not be in terms of its position but in terms of what action the information constrains.

That a correspondence relation is important in some tasks but not others is not a new finding. For tasks in which there are both spatial and other correspondence relations (e.g., color), the spatial correspondence yields a Simon effect when color is the relevant dimension; but color does not yield a "color-Simon" effect when position is the relevant variable (Brebner, 1979). Simon, Hinrichs, and Craft (1970) and Hasbroucq and Guiard (1991) presented other examples of how changing the task alters the participants' exploitation of the available correspondence relations. However, this possibility is not always recognized. Umiltà and Liotti (1987), using a paradigm in which the absolute or relative position of the stimulus was precued, had participants make a left–right response to a particular shape, regardless of its (absolute or relative) position (their Experiment 3). When the precue–stimulus interval was 500 ms, a Simon effect involving the relative stimulus position was observed; it disappeared, however, when the interval was 0 ms. The absence of a Simon effect was explained tentatively by assuming that the two left–right stimulus codes were both available but had somehow cancelled each other out. This explanation, however, implicitly assumed that a change in the experimental task does not affect attention to the available spatial correspondence relations. Instead, it is likely that different tasks impose different constraints on the pick-up of the relevant information (Newell & McDonald, 1994) and, as a consequence, affect the exploited correspondence relations.

Similarly, other research suggests that the instructions that the participants receive may determine which of the available compatibilities becomes operative. For example, Hommel (1993; see also Morin & Grant, 1955) induced a compatibility effect with regard to the action goal of the response (i.e., the perceived consequences of the response). In his experiment, pressing a left or right key resulted in the illumination of a left or right light. When the participants were instructed to illuminate a particular light in response to the imperative stimulus, the spatial correspondence between the position of the stimulus and the position of the effector was overruled by the spatial correspondence between the light and the stimulus.

Moreover, individual participants may differ in the correspondence relations that they exploit. Guiard (1983, Experiment 3) had participants rotate a steering wheel in response to the pitch of an auditory stimulus. Given a proximal hand position on the wheel, a left movement resulted in a right movement of the distal part of the wheel and vice versa. The stimulus was presented to the left ear or to the right ear, and it was found that the ear stimulated did not significantly affect the RTs. However, the data from individual participants showed that about half of the participants exploited the compatibility relation afforded by the direction of the movement of the hands, whereas the other participants exploited the direction of the rotation of the wheel. What was a compatible S–R relation for some participants was an incompatible one for the other participants.

Together, these findings demonstrate that identical S–R mappings can lead to different compatibility relations, depending on task constraints and individual differences. This makes clear that spatial S–R compatibility effects are not due simply to the correspondence between the left–right positions of the stimulus and the response, but that participants are able to exploit selectively the different S–R correspondences that best serve the experimental constraints. In our Experiment 2, the participants appeared to exploit the spatial correspondence between the stimulus and the target; whereas in Experiment 3, they appeared to exploit the spatial correspondence between the stimulus and the hand. Thus, there is clearly no unconditional, automatic, activation of responses that exists over all choice RT situations. It is possible to induce the preferred S–R mappings experimentally; and what constitutes a compatible S–R combination in one situation may become an incompatible one when a new task has to be performed, which is exactly what we found in our experiments.

Positive and Reversed Simon Effects

That a target of movement can be different both from the location of the imperative stimulus and from the initial effector location permits the unpacking of S–R correspondence into the three relations described in Table 1. We think that the recognition of the three relations makes certain findings that appear anomalous emerge as simple. In this section, we apply our logic to the positive and negative versions of the Simon effect.

Since 1975, when Hedge and Marsh reported a reversal of the Simon effect, the questions of whether and how task-irrelevant spatial relations participate in compatibility effects have been the focus of considerable attention. In the Hedge and Marsh experiment, left and right response keys, which were green and red, respectively, were positioned under left and right stimulus lights that could each be illuminated as red or green. The participants moved a single hand from a home key to a response key. Under instructions to press the key of the same color as the stimulus, the participants exhibited a Simon effect; the red button, for example, was pressed faster when it corresponded spatially

[3] We use the term *signal* in an operational sense only. Whether a stimulus (or information) specifies, constrains, or signals actions and whether it does the same in both compatible or incompatible conditions is an issue that we consider elsewhere (Michaels & Stins, 1997).

with the red stimulus. However, under instructions to press the opposite-color key, pressing the left, green key, for example, was faster when the (red) stimulus was on the right. This observation has been termed a *negative* or *reversed* Simon effect.

Various theories have been put forth to account for these findings. Hedge and Marsh themselves appealed to a logical recoding hypothesis in which the respond-with-the-opposite-color instruction was automatically generalized to position. Simon, Sly, and Vilapakkam (1981) favored an explanation in terms of display–control arrangement, citing the importance of the alignment of stimulus and response lights of the same color. Hasbroucq and Guiard (1991) argued that S–S congruity was operative, much like in a Stroop task; responses are faster when stimuli on the relevant (color) and irrelevant (position) dimensions agree; when they do not, there is a time cost to pay in stimulus identification. Kornblum's (1992) model sees little room for dimensional overlap between color and position and, thereby, locates the effect in the response selection stage of processing rather than in the stimulus identification stage. Most recently, Lu and Proctor (1994), using additive-factors logic, presented results that also locate the effect of an irrelevant spatial dimension in the response–selection stage.

It should be noted that our Experiment 1 meets some of the operational criteria for a negative Simon effect: In the S–T consistent condition, responses with the hand ipsilateral to the illuminated stimulus were initiated faster than responses with the hand contralateral to the illuminated stimulus and, in the S–T inconsistent condition, responses from the hand *contralateral* to the illuminated stimulus were initiated faster than those from the hand ipsilateral to the illuminated stimulus. In short, if one looks only at the stimulus and the hand and ignores the target, our results resemble the positive and negative Simon effects observed by Hedge and Marsh (although in our study, there is arguably only *one* stimulus dimension *and* that dimension is task relevant).

We believe that the concept of target (i.e., a place at which a movement is directed), used to explain the results of Experiment 1, may also be applied to the Hedge and Marsh findings. The parallel is as follows: In our Experiment 1, the illuminated stimulus constituted the preferred target of the reach; if the preferred target position coincided with the actual target position (S–T consistent), RTs were faster. Also there was an ipsilateral advantage in that movements with the hand ipsilateral to the (actual) target were initiated faster than movements with the hand contralateral to the target. We argue that, in the Hedge and Marsh experiment, the response button of the same color as the stimulus light constituted the preferred target; responses in the direction of that button were faster than in the direction of the other button. In addition, there was an ipsilateral advantage for developing a preferred target; the emergence of the same colored button as the preferred target was faster when the response button was ipsilateral to the stimulus.

On these accounts, we claim that responses in the direction of the preferred target are faster than responses elsewhere, where the preferred target is that which corresponds to the imperative stimulus on whatever dimension (location in the case of our Experiment 1 or color in the case of Hedge and Marsh) the participant exploits, given task demands. Moreover, such an effect can masquerade as an interaction between correspondences on relevant and irrelevant stimulus dimensions (i.e., a positive and negative Simon effect).

S–R or S–S Effects?

The separation of effector location and target location, as occurs with genuine movement, also casts a new light on the domain of dimensional overlap and coding theory. It suggests that these compatibility accounts may not be about stimulus–response relations at all, but about how one set of stimuli (e.g., color or position of the imperative stimuli) is related to another set of stimuli (color or position of response buttons), that is, how well one stimulus characteristic corresponds to another stimulus characteristic. So-called *response codes* in coding theory and dimensional overlap seem more like stimulus codes. The arbitrariness of the usual distinctions between stimulus and response characteristics is plain in the Hasbroucq and Guiard (1991) experiments in which the color of a light is considered to be a stimulus characteristic, and the color of a button is considered to be a response characteristic. "Response" variables, such as color or relative direction, bear little resemblance to the variables that movement scientists posit to describe the characteristics of an action, such as what muscles or coordinative structures are involved, what forces or torques need to be applied, what type of oscillator is assembled, and so on.

Given this reading, response should be conceived as performing an action (e.g., a movement directed at a particular place) resulting in the accomplishment of a particular goal, for example, the grasping of an object, reaching a particular place, or even pressing a key. Similarly, target should also be broadly conceived, as one of several possible movement goals because there are certainly other characteristics in addition to terminal location that would affect the manner of coordination. In the case of movement, the same target may be reached in innumerable ways. This is nicely illustrated in lever turning in which if the goal is to turn a lever to some position, the manner of the initial grasp is affected both by the current orientation of the lever and its desired end point (e.g., Rosenbaum et al., 1990). Thus, we view our compatibility effects for ipsilateral targets and hands as a bona fide S–R compatibility effect and not as an S–S effect.

We conclude that the importance of coordinated action to S–R compatibility has been ignored because when a finger rests on a button, there is literally no room left between target and effector for coordination effects to appear. Instead, attention has been directed most often to what determines a target, and these S–S compatibility effects have been passed off as S–R effects. Where effects of the action system have been sought, such as in experiments by Tipper et al. (1992), Spijkers (1990), or our own work on postural and positional determiners of compatibility, they have been

found. The thrust of our argument is that theories of S–T compatibility should abandon response codes in favor of a serious consideration of the coordination of action. Elsewhere (see Michaels & Stins, 1997, for a review of our ecological approach to compatibility), we have made parallel arguments for stimulus codes and perceptual information. Our collective aim has been to direct attention to coordinated action, sensory information, and their relation, which may serve a basis for theorizing about fundamental relationships between an actor and the environment, such as those evidenced in compatibility effects.

References

Bauer, D. W., & Miller, J. (1982). Stimulus–response compatibility and the motor system. *Quarterly Journal of Experimental Psychology, 31A,* 367–380.

Bernstein, N. (1967). *The coordination and regulation of movement.* London: Pergamon.

Brebner, J. (1979). The compatibility of spatial and non-spatial relationships. *Acta Psychologica, 43,* 23–32.

de Graaf, J. B., Sittig, A. C., & Denier van der Gon, J. J. (1994). Misdirections in slow, goal-directed arm movements are not primarily visually based. *Experimental Brain Research, 99,* 464–472.

Fischer, B., & Weber, H. (1992). Characteristics of "anti" saccades in man. *Experimental Brain Research, 89,* 415–424.

Guiard, Y. (1983). The lateral coding of rotations: A study of the Simon effect with wheel-rotation responses. *Journal of Motor Behavior, 15,* 331–342.

Hasbroucq, T., & Guiard, Y. (1991). Stimulus–response compatibility and the Simon effect: Toward a conceptual clarification. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 246–266.

Hedge, A., & Marsh, N. W. A. (1975). The effect of irrelevant spatial correspondence on two-choice response time. *Acta Psychologica, 39,* 427–439.

Heister, G., Schroeder-Heister, P., & Ehrenstein, W. H. (1990). Spatial coding and spatio-anatomical mapping: Evidence for a hierarchical model of spatial stimulus–response compatibility. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 117–143). Amsterdam: North-Holland.

Hommel, B. (1993). Inverting the Simon effect by intention: Determinants of direction and extent of effects of irrelevant spatial information. *Psychological Research, 55,* 270–279.

Jackson, S. R., Jackson, G. M., & Rosicky, J. (1995). Are non-relevant objects represented in working memory? The effect of non-target objects on reach and grasp kinematics. *Experimental Brain Research, 102,* 519–530.

Klapp, S. T., Greim, D. M., Mendicino, C. M., & Koenig, R. S. (1979). Anatomic and environmental dimensions of stimulus–response compatibility: Implication for theories of memory coding. *Acta Psychologica, 43,* 367–379.

Kornblum, S. (1992). Dimensional overlap and dimensional relevance in stimulus–response and stimulus–stimulus compatibility. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior: Part 2* (pp. 743–777). Amsterdam: North-Holland.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility–A model and taxonomy. *Psychological Review, 97,* 253–270.

Ladavas, E. (1987). Influence of handedness on spatial compatibility effects with perpendicular arrangement of stimuli and responses. *Acta Psychologica, 64,* 13–23.

Lu, C.-H., & Proctor, R. W. (1994). Processing of an irrelevant location dimension as a function of the relevant stimulus dimension. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 286–298.

Michaels, C. F. (1988). S–R compatibility between response position and destination of apparent motion: Evidence of the detection of affordances. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 231–240.

Michaels, C. F. (1989). S–R compatibilities depend on eccentricity of responding hand. *Quarterly Journal of Experimental Psychology, 41A,* 263–272.

Michaels, C. F., & Schilder, S. (1991). Stimulus–response compatibilities between vertically oriented stimuli and horizontally oriented responses: The effects of hand position and posture. *Perception & Psychophysics, 49,* 342–348.

Michaels, C. F., & Stins, J. F. (1997). An ecological approach to S–R compatibility. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus–response compatibility* (pp. 333–360). Amsterdam: North-Holland.

Morin, R. E., & Grant, D. A. (1955). Learning and performance on a key-pressing task as a function of the degree of spatial stimulus–response correspondence. *Journal of Experimental Psychology, 49,* 39–47.

Newell, K. M., & McDonald, P. V. (1994). Information, coordination modes and control in a prehensile force task. *Human Movement Science, 13,* 375–391.

Nicoletti, R., Umiltà, C., & Ladavas, E. (1984). Compatibility due to the coding of the relative position of the effectors. *Acta Psychologica, 57,* 133–143.

Proctor, R. W., & Reeve, T. G. (Eds.). (1990). *Stimulus–response compatibility: An integrated perspective.* Amsterdam: North-Holland.

Proctor, R. W., Van Zandt, T., Lu, C.-H., & Weeks, D. J. (1993). Stimulus–response compatibility for moving stimuli: Perception of affordances or directional coding? *Journal of Experimental Psychology: Human Perception and Performance, 19,* 81–91.

Riggio, L., Gawryszewski, L. G., & Umiltà, C. (1986). What is crossed in crossed-hands effects? *Acta Psychologica, 62,* 89–100.

Rosenbaum, D. A., Marchak, F., Barnes, H. J., Vaughan, J., Slotta, J. D., & Jorgensen, M. J. (1990). Constraints for action selection: Overhand versus underhand grip. In M. Jeannerod (Ed.), *Attention and performance: Part 13* (pp. 321–342). Hillsdale, NJ: Erlbaum.

Simon, J. R. (1969). Reactions towards the source of stimulation. *Journal of Experimental Psychology, 81,* 174–176.

Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 31–86). Amsterdam: North-Holland.

Simon, J. R., Craft, J. L., & Webster, J. B. (1971). Reaction time to onset and offset lights and tones: Reactions toward the changed element in a two-element display. *Journal of Experimental Psychology, 89,* 197–202.

Simon, J. R., Hinrichs, J. V., & Craft, J. L. (1970). Auditory S–R compatibility: Reaction time as a function of ear–hand correspondence and ear–response–location correspondence. *Journal of Experimental Psychology, 86,* 97–102.

Simon, J. R., & Rudell, A. P. (1967). Auditory S–R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology, 51,* 300–304.

Simon, J. R., Sly, P. E., & Vilapakkam, S. (1981). Effect of com-

patibility of S–R mapping on reaction toward the stimulus source. *Acta Psychologica, 47,* 63–81.

Spijkers, W. A. C. (1990). Response selection and motor programming: Effects of compatibility and average velocity. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 297–309). Amsterdam: North-Holland.

Spijkers, W. A. C., & Sanders, A. F. (1984). Spatial accuracy and programming of movement velocity. *Bulletin of the Psychonomic Society, 22,* 531–534.

Tipper, S. P., Lortie, C., & Baylis, G. C. (1992). Selective reaching: Evidence for action-centered attention. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 891–405.

Umiltà, C., & Liotti, M. (1987). Egocentric and relative spatial codes in S–R compatibility. *Psychological Research, 49,* 81–90.

Umiltà, C., & Nicoletti, R. (1990). Spatial stimulus–response compatibility. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 89–116). Amsterdam: North-Holland.

Van Duren, L. L., & Sanders, A. F. (1988). On the robustness of the additive factors stage structure in blocked and mixed choice reaction designs. *Acta Psychologica, 69,* 83–94.

Wallace, R. J. (1971). S–R compatibility and the idea of a response code. *Journal of Experimental Psychology, 88,* 354–360.

Wallace, R. J. (1972). S–R compatibility effects involving kinesthetic cues. *Journal of Experimental Psychology, 93,* 163–168.

Weeks, D. J., Proctor, R. W., & Beyak, B. (1995). Stimulus–response compatibility for vertically oriented stimuli and horizontally oriented responses: Evidence for spatial coding. *The Quarterly Journal of Experimental Psychology, 48A,* 367–383.

Zelaznik, H. N., Schmidt, R. A., & Gielen, S. C. A. M. (1986). Kinematic properties of rapid aimed hand movements. *Journal of Motor Behavior, 18,* 353–372.

Received June 6, 1995
Revision received October 17, 1995
Accepted February 12, 1996 ■